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APOLLO RCS POSITIVE EXPULSION TANKAGE
PRODUCT IMPROVEMENT PROGRAM
FINAL REPORT - TASK F

INTEGRATION AND VERIFICATION
OF SOLUTIONS

Bell Report No. 8514-928007
10 January 1970

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FOREWORD

This report is one of a series of task reports which present the results of a program performed by Bell Aerospace Company during the period July 1967 through September 1969 under Contract NAS9-7182 for the National Aeronautics and Space Administration, Manned Spacecraft Center. Mr. Darrell Kendrick was Technical Monitor of the program for NASA. The Bell Aerospace Program Manager was Mr. R. K. Anderson.

The purpose of the program was to improve and update the Apollo RCS positive expulsion propellant tank assemblies in the areas of performance, reliability, and mission duration. The program effort was divided into the following major tasks, each of which is reported separately.

Task A - Historical Summary Report - A chronological summary of the evolution of the Command, Service, Lunar Module, and other related tankage was prepared. This summary includes data on all configurations considered under the applicable programs and describes related IR&D work at Bell Aerospace Company.

Task B - Long-Term Compatibility Testing - The purpose of this task was to determine the useful operating lifetime of the Apollo configuration RCS tanks as applicable to a mission of extended duration with a specific goal of 12 months. This task consisted of the following sub-tasks:

B-1: Tank Assembly Storage: Three tank assemblies were stored with propellant (N_2O_4, MMH, 50/50 fuel blend) for 12 months at operating pressure. At the end of this time, each tank was subjected to a complete propellant expulsion followed by disassembly and evaluation.

B-2: Bladder Material Compatibility Testing: Teflon bladder material specimens were subjected to rolling of buckled fold tests after 24 hours, 6 months, and 12 months exposure to N_2O_4, MMH, and 50/50 fuel.

B-3: External Flange Seal Evaluation: The effect of initial flange bolt tightening and retightening techniques on the rate of torque decay was evaluated during a 1-year shelf storage period.

Task C - Correlation of Referee Fluid and Propellant in Vibration Testing - The objective of this task was to verify that vibration testing of the Apollo-type bladder with referee fluid is representative of vibration testing with actual propellants. To develop a correlation with sufficient accuracy, the following three areas of testing were pursued:

C-1: Vibration tests were conducted with referee fluid in a plexiglass tank to define the response characteristics of the bladder as affected by ullage level, direction of excitation, and vibration input level.

C-2: Rolling of buckled fold tests were conducted on bladder material specimens to compare endurance in referee fluids with endurance in propellants.

C-3: Full-scale vibration testing was performed on a Lunar Module RCS oxidizer tank with N_2O_4.

Task D - Elimination of Permeation and Bubble Formation - The objective of this task was the elimination, or reduction, of bladder permeation and the associated problem of bubble formation within the bladder. This task included two principal areas of effort:

D-1: Development of Permeation Barrier: This sub-task consisted of design and fabrication of a Teflon bladder with an aluminum foil laminate as a permeation barrier. This bladder, which was of the Service Module oxidizer configuration, was also designed to function in an undersized configuration.

D-2: Elimination of Bubble Formation in Current Apollo Bladder Configuration: Experiments were conducted on both model and full-scale tanks to examine bubble formation phenomena as a function of such variables as temperature, pressure and ullage level. Data from these tests were used to provide an emperical basis for a better understanding of the mechanisms involved and the effect of each on bubble formation.

Task E - Solution of Command Module and Service Module Bladder Repositioning Problem - The objective of this task was to increase expulsion cycle life of these bladders by eliminating damage due to post-expulsion repositioning.

E-1: Service Module Oxidizer Bladder: The approach used to solve this problem was the use of an undersized configuration similar to that used on the Lunar Module RCS tanks to solve the same problem.

E-2: Command Module Bladder: This problem was associated with the twist mechanism involved in a horizontally mounted tank during the fill cycle. A solution to this problem could not be found within the constraints of the program.

Task F - <u>Integration and Verification of Solutions</u> - The objective of this task was to devise a series of formal tests to demonstrate compliance of design changes from Tasks D-1 and E with the requirements of the applicable Apollo contractor procurement specification.

Service Module oxidizer bladders of the undersized configuration with an aluminum foil laminate were subjected to qualification-level vibration testing and were to be subjected to 20 propellant-expulsion cycles. However, problems occurred during vibration testing which resulted in bladder failure and this task could not be completed within the limits of this program.

Since the Command Module bladder twist problem was not solved (Task E-2), no Command Module tank testing was performed in Task F.

This report covers the effort performed under Task F. The other major tasks are reported individually as follows:

Task	Report Number	Title
A	8514-927002	Historical Summary Report
B	8514-928004	Long-Term Compatibility Testing
C	8514-928005	Correlation of Referee Fluid and Propellant In Vibration Testing
D	8514-928003	Elimination of Permeation and Bubble Formation
E	8514-928006	Solution of Command Module and Service Module Bladder Repositioning Problems

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I. INTRODUCTION

The objective of this task was to devise a series of formal tests with NASA-approved procedures to demonstrate compliance of design changes from Tasks D-1 and E of this program with the dynamic and expulsion requirements of the applicable Apollo contractor procurement specifications.

Service Module oxidizer (SMO) bladders of the same undersized configuration as the Lunar Module bladder and containing an aluminum foil laminate were to be subjected to vibration, 30-day propellant exposure, and propellant expulsion testing. Three bladders of this design were subjected to vibration testing and failed during this phase of the test program. Consequently, the propellant exposure and expulsion tests were not performed. It has been concluded that the failure of these bladders does not invalidate the design concept, but rather points out that the bladder film thickness was too great to perform well with the present method of attachment to the diffuser tube.

Since a satisfactory solution to the Command Module bladder twist problem was not found in Task E, no Command Module tank testing was performed in Task F.

II. SUMMARY

Three SMO bladders of the undersized configuration used on Lunar Module RCS Tanks, with aluminum foil permeation barriers, were subjected to Apollo SMO specification vibration tests. The laminate constructions of the bladders were similar (20% Codispersion Teflon - Aluminum Foil - FEP Teflon) with the thickness of each material and the placement of the aluminum foil within the laminate being the variables.

All three bladders experienced failures during vibration testing. However, the failures could not be attributed to vibration fatigue damage. Duplication of the bladder failures with laboratory specimens indicated that the failures were caused by repetitive flexing followed by shock-type loads or low-temperature flexing.

All bladders showed minimal wear except in the failed areas. No excessive wear was noted at the liquid surface where the Apollo-type Teflon (6-mil-thick) bladder designs had shown the greatest damage. Therefore, the SMO undersized bladder concept with an aluminum permeation barrier is valid and needs redesign only to decrease its stiffness (thickness) and/or improve the method of attachment to the diffuser.

III. DISCUSSION

A. Test Description

1. Procedure

The aluminum foil laminate bladders were subjected to the Apollo SMO specification vibration test requirements. The tests were conducted in accordance with the procedures specified in Bell Report Number 8514-928002, "Model 8514 Service Module Oxidizer Type Positive Expulsion Propellant Tank, Integration and Verification Test Procedure For." The vibration tests consisted of sinusoidal and random vibration in the tank longitudinal (X) axis and lateral (Z) axis.

The testing was performed with a 7.5% volumetric ullage, using Freon-T F as the simulated propellant. The gas side of the bladder was pressurized to 180 psig with nitrogen gas.

Helium leakage tests at 10 psi ΔP (internal-to-external) were conducted on each bladder before vibration and after each axis of vibration. The gas side of the bladder was monitored with a halogen leak detector for evidence of Freon after sinusoidal vibration and after each random vibration equalization burst.

2. Test Hardware

The vibration test program was conducted using Model 8514 Tank Assembly P/N 8514-471001-1 which consisted of:

SMO Tank Shell	P/N 8271-471036-7	S/N 12
SMO Diffuser	P/N 8271-471233-15	S/N 30

Aluminum Foil Laminate Bladders:

P/N 8514-471008-1	S/N 69-1
P/N 8514-471008-1	S/N 70-1
P/N 8514-471008-1	S/N 68-1

The bladder design was of the Service Module Oxidizer (SMO) size except that the cylindrical section was 2% undersized diametrally as shown in Figure 1. The laminate constructions are shown in Figure 2. A photograph of a typical bladder is shown in Figure 3.

SMO tank vibration test fixtures were used. All vibration tests were conducted on the MB Model C-125 shaker.

3. Vibration Spectrum

The vibration spectrum for all tests was the Apollo SMO specification requirement as follows:

a. Sinusoidal Vibration - 5 min/axis

5 to 33 Hz	0.036 inch D.A.
33 to 2000 Hz	2 g peak

Constant octave sweep from 5 to 2000 Hz in approximately 5 minutes.

b. Random Vibration - 15 min/axis

0.035 to 0.35 g^2/Hz	10 to 100 Hz
0.35 g^2/Hz	100 to 250 Hz
0.35 to 0.03 g^2/Hz	250 to 2000 Hz

4. Test Instrumentation

The tank shell was instrumented with accelerometers for X-axis vibration as shown in Figure 4 and for Z-axis vibration as shown in Figure 5.

B. Test Results

1. Bladder S/N 69-1

Bladder S/N 69-1 successfully completed X-axis sinusoidal and random vibration and Z-axis sinusoidal vibration tests. Bladder failure occurred during Z-axis random vibration. Bladder leakage rates are contained in Table 1 and vibration test times are contained in Table 2.

Random equalization runs in the Z axis were completed without incident. However, when the full-level random vibration test was started, a large overtest condition was encountered due to a vibration test console component failure. A 51 g shock input in one direction followed by a 37 g input in the opposite direction was applied along the Z axis. At this time, an automatic overload circuit shut the vibration test equipment down. Peak responses on the tank due to the shock input are listed in Table 3.

Testing was temporarily suspended and the gas side of the bladder was checked for evidence of Freon vapors. No vapor could be detected, so testing was resumed. After 1 minute and 47 seconds of full-level random duration testing, a decrease in tank pressure was noted. The test was terminated and Freon vapor was detected on the gas side of the bladder.

The tank assembly was drained, purged, and disassembled. A peripheral slit, approximately 2 inches long, was found at the top of the bladder at the edge of the retainer washer. This slit was in line with the Z axis which was the direction of excitation. A highly stressed area was found at the edge of the retainer washer directly opposite the slit. (Refer to Figure 6 for photograph of bladder failure.) As can be seen in Figure 7, the remainder of the bladder was in excellent condition.

A complete inspection of all the tank hardware disclosed no abnormality which could have caused or contributed to the failure.

During the analysis of the failure in Bladder S/N 69-1, several modes of failure were eliminated immediately. There was no evidence of mechanical damage or material defect. The failure characteristics observable in a microtome cross-section were of a nature that could not result from puncture or other mechanical damage or from laminate defects. (See Figure 8.)

Rolling of a buckled fold (vibration fatigue damage) can be eliminated from consideration by studying the characteristics of the failure at the bladder surfaces and through the cross-section. There was no rolling fold valley or localized depression leading into or paralleling the failure at any point. There were no striations or white ridges present.

These features always accompany rolling fold damage to Teflon. Rolling fold action of sufficient duration to cause a total rupture invariably elongates or distorts the codispersion layer. (Refer to Figure 8.) The edges of the codispersion layer of the S/N 69-1 failure were even and abrupt and showed no elongation or deformation. (See Figure 8.) The S/N 69-1 failure was reproduced in the laboratory by subjecting specimens to repetitive flexing (100,000 cycles) followed by a sudden shock sufficient to rupture the codispersion layer. As can be seen in Figure 8, the mode of failure of the laboratory shock specimens was very similar to that of Bladder S/N 69-1.

The foregoing evidence led to the conclusion that the previously described overtest (shock impulse) was responsible for the failure of Bladder S/N 69-1.

2. Bladder S/N 70-1

As a result of the failure of Bladder S/N 69-1, Bladder S/N 70-1 was diverted from Task E so that the integration and verification test program could continue. Bladder S/N 70-1 had been subjected to 8 Freon TF expulsion cycles in Task E. (Refer to Report No. 8514-928006.) As can be seen in Figure 2, the laminate configuration of S/N 70-1 was identical to that of S/N 69-1.

Bladder S/N 70-1 successfully completed sine and random vibration in both longitudinal (X) and lateral (Z) axes without any indication of bladder failure. The total vibration time for this bladder is shown in Table 2.

After completion of each axis of vibration testing, the tank was vented, the bladder expanded, and the tank drained and purged. This was followed in each case by a bladder helium leakage test. In attempting the final helium leakage test, the bladder was found to have an excessive leakage rate, indicating bladder failure.

There had been no indication of failure prior to the final bladder leakage test. The gas exiting from the gas inlet port during post-vibration venting and during bladder re-expansion was monitored for presence of Freon-TF vapors and none were detected.

The bladder assembly was removed from the tank for evaluation and the bladder was found to have a 0.007-inch-long rupture located in the retainer hemisphere 1.75 inches from the top of the bladder. (See Figure 9.) The failure was adjacent to an area which exhibited noticeable damage to the FEP laminate located on the outer side of the foil. The inner (codispersion) side showed only a ridge which contained the rupture. Other damage to the bladder was minimal as shown in Figure 10.

The failure area was removed from the bladder and examined microscopically with the following observations (see Figure 11):

a. The rupture was adjacent to an area which had been somewhat damaged by rolling of buckled fold action as evidenced by some buckling and necking down of the codispersion layer. (See Figure 11B.)

b. Although the failure occurred in the vicinity of an area which displayed some fatigue damage due to vibration, the failure area itself did not exhibit the normal evidence of fatigue due to repetitive folding. For example, Figure 11A does not show the reduction in area (necking down) exhibited in the adjacent area shown in Figure 11B.

c. The failure had the typical characteristics of a brittle failure. The rupture of the codispersion was abrupt with no reduction in thickness and no observable birefringence which would indicate residual stresses when studied under polarized light.

d. The FEP laminate at the point of rupture was broken with very little or no delamination, indicating a lack of repetitive damaging action.

e. A microscopic study of the cross-sectional profile of the rupture revealed that the failure occurred when the outside surface of the bladder in the failure area was placed in tension. This study also indicated that the sub-laminates of the codispersion layer had been slightly distorted inward prior to failure.

The above observations led to the conclusion that the rupture of bladder S/N 70-1 was not a fatigue-type caused by vibration testing. Rather, it appeared to be caused by a mechanism involving a single cycle (or very few cycles) which involved reversal of stresses in the film such as the draining, purging,and bladder expansion at the conclusion of the Z-axis vibration.

Since it is known that such a mechanism can cause failure in Teflon bladder material at low temperatures, the test logs were reviewed to determine whether a low-temperature condition accompanied by bladder motion due to internal pressure could have occurred during post-test bladder servicing. The results of this review, together with laboratory simulation tests, indicated that such a condition could have easily existed due to vaporization of trapped pockets of Freon-TF in the relatively stiff bladder folds which could have lowered the bladder temperature to as low as 20°F. Since no indication of bladder failure was observed during the Z-axis vibration test,or after venting the pressure following the test, it was concluded that the failure must have occurred after the post-test bladder draining, and most probably during the purging.

Even though the failure analysis revealed that the Bladder S/N 69-1 and 70-1 failures were not directly caused by vibration, the initial findings indicated that a thinner, more-compliant film may be more-desirable from the standpoint of lowering stresses in the foil laminate and making bladder installation and servicing less critical.

In the interest of developing a thinner more-compliant film, the following two candidate laminate constructions were evaluated:

Configuration No. 1	Configuration No. 2
2 mil TFE	3-1/2 mil Codispersion (20%)
1-1/4 mil FEP	1-1/4 mil FEP
1/4 mil Al Foil	1/2 mil Al Foil
3-3/4 mil FEP	4-3/4 mil FEP
7-1/4 mil Total	10 mil Total

Specimens of each construction were subjected to two types of strain recovery tests. The first test consisted of applying 2% uniaxial strain several times with the strain imposed each time for 1 minute and then removed for 5 minutes. Specimen length was measured with an optical comparator after each 5-minute recovery period. After 10 cycles, each construction exhibited very little strain recovery.

The second strain recovery test consisted of applying a 2% uniaxial strain to each specimen and retaining this strain for 24 hours. The strain was then removed and specimen length was measured after recovery times of 5 minutes, 1 hour, 2 hours, 8 hours, 24 hours, 72 hours,and 90 hours. Construction No. 1 showed a strain recovery of 50% after 1 hour and 70% after 72 hours, while Construction No. 2 showed 33% recovery after 1 hour and 40% after 90 hours.

Rolling of buckled fold tests performed at 14 cps in water at 75°F indicated a cycle life of 5700 to 12,000 cycles for Construction No. 1 and 9000 to 13,500 + cycles for Construction No. 2.

Based on the above test results,it was concluded that the ratio of foil laminate thickness to total film thickness in each of the candidate constructions was too great to allow dependable strain recovery on a multiple cycle basis which is necessary in an undersized bladder configuration. Also, as would be expected due to its greater film thickness, the No. 2 construction exhibited a markedly better roll-fold cycle life.

As a result, it was decided to fabricate and vibration test a full-scale SMO size bladder of the undersized configuration using the No. 2 construction with 1/4 mil aluminum foil to allow better strain recovery.

3. Bladder S/N 68-1

Bladder S/N 68-1 was fabricated using the previously discussed laminate configuration. (Refer to Figure 2.)

Bladder S/N 68-1 successfully completed sine and random vibration in the X axis. The normal 15-minute random vibration in the X axis was performed in two parts of 5 and 10 minutes, respectively. After the initial 5-minute random test, the tank was drained and purged and a bladder leakage test was performed to determine the amount of foil damage which could be reasonably expected as a result of launch and boost vibration in an actual mission. As can be seen in Table 1, there was essentially no difference in the pre and post 5-minute random vibration leakage test results. The tank was then reloaded and the remaining random and sine vibration was completed in the X axis. Again the bladder leakage test revealed little or no damage to the bladder. (Refer to Table 1.)

The Z-axis sine vibration was completed without incident. After 1 minute of random vibration in the Z axis, bladder failure was experienced. Bladder leakage rates are contained in Table 1 and total vibration time is shown in Table 2.

The tank assembly was disassembled and a slit approximately 1 inch long was found at the top of the bladder at the edge of the retainer washer. (See Figure 12.) This slit was in line with the Z axis and closely approximated the Bladder S/N 69-1 failure. With the exception of the failure itself, very little damage had occurred to the bladder or the foil laminate. Figure 13 shows the bladder with interior lighting to highlight damage to the foil laminate.

As can be seen in Figure 8, the failure appearance of Bladder S/N 68-1 was essentially identical to that of Bladder S/N 69-1. As previously discussed, this type of failure was duplicated by laboratory tests of bladder specimens which consisted of subjecting specimens to repetitive flexing followed by a shock-type load.

An oscillograph playout of all Bladder S/N 68-1 vibration time disclosed no shocks or other anomalous inputs. However, the Z-axis random vibration showed high responses on the boss (top) end of the tank and, in particular, the response of accelerometer No. 6 on the trunnion face was saturated (estimated to be 125 grms). An estimation of the grms levels from the time history records for Bladder S/N 68-1 is given in Table 4. A comparison of these estimated levels with those measured on Bladder S/N 69-1 and 70-1 tanks (Table 4) showed an increasing difference, progressing from the flange end (bottom) to the boss end (top) of the tank. The estimated response of the trunnion face (longitudinal direction) exceeds that of S/N 69-1 by a factor of 2.3 and that of S/N 70-1 by 3.6. No reason for the apparent high levels at the boss end of Bladder S/N 68-1 tank was found. The Teflon insert used to support the tank boss in the Z-axis vibration test fixture was not visibly worn; however, the top (trunnion) end of the tank shell was noted by test personnel to be extremely warm just after termination of the test, which would indicate that the Teflon insert may have been slightly loose during the test.

The exact cause of the Bladder S/N 68-1 failure is unknown. However, because the failure characteristics are identical to that of Bladder S/N 69-1, it appears that the abnormally high response levels during the Z-axis random vibration were responsible for the bladder failure.

IV. ANALYSIS OF TEST RESULTS

Two of the three bladders failed before completion of vibration test with both failures consisting of long slits at the edge of the retainer washer which is the point of attachment of the bladder to the diffuser at the top end of the tank. Both of these bladders had been subjected to overtest conditions during lateral axis vibration; S/N 69-1 had been subjected to high shock loading due to equipment malfunction and S/N 68-1 had experienced responses of two to three times the normal response output, apparently due to a loose teflon bushing at the top of the tank.

The third bladder (S/N 70-1), which had undergone eight liquid expulsions plus an extra removal and installation into a shell prior to vibration, completed the vibration test satisfactorily. Its failure, unlike the others, consisted of a pinhole caused by reversal of a fold in the bladder at low temperature during post-test servicing.

None of the three failures showed the characteristics of fatigue damage normally found in teflon bladder film; there was no necking down of the laminates at the point of failure and no appreciable delamination in the failure area. This was borne out by extensive laboratory testing which could reproduce the S/N 69-1 and S/N 68-1 failures only by repeated flexure followed by shock loading, and the S/N 70-1 failure only by reversal of a fold at low temperature (20°F).

There was no evidence of appreciable rolling-fold damage at the apex of double-buckled folds, which has been found to be the primary limiting factor in the fatigue life of Apollo-type teflon bladders in vibration. With the exception of the immediate failure area, each bladder showed minimal damage due to vibration.

All the evidence from the bladder evaluations and the laboratory testing indicates that bladder stiffness was a major factor in all three failures. It appears that, although a thicker bladder film appreciably increases the fatigue life of teflon bladders in the rolling-of-buckled fold mechanism, the added stiffness can create other limiting factors in bladder service life. As the failures of S/N 69-1 and S/N 70-1 indicated, the method of attachment of the bladder ends to the diffuser becomes more critical with a stiffer bladder. In addition, thinner, more-compliant film constructions decrease the danger of damage during assembly and installation into the tank and during servicing operations.

It should be pointed out that the actual film thicknesses of the bladders tested was appreciably greater than the design requirements. The measured thicknesses of S/N 69-1 and S/N 70-1 were 14.4 and 15.3 mil, respectively, compared to the design thickness of 12.5 mil. S/N 68-1 had an actual film thickness of 12.7 mil, compared to the design thickness of 10.0 mil.

When examined after testing, all three bladders appeared to be in excellent condition in the undersized cylindrical section, including bladder S/N 70-1 which had eight liquid expulsions prior to vibration. Thus, the combination of aluminum foil laminate with the undersized configuration is considered to be a valid design concept.

As shown in Table 1, bladder S/N 68-1 gave strong evidence that the amount of vibration experienced in a normal launch/boost dynamic environment would do effectively no damage to an aluminum foil permeation barrier in a teflon bladder. The 0.1 scc/15 minutes leakage measured after 5 minutes of random vibration in the longitudinal axis is approximately 0.1% of the average actual bladder leakage rate experienced during acceptance testing of Apollo SMO tanks delivered as flight hardware.

Using the relationships developed as part of Task D of this program and reported in Bell Report 8514-928003, it would take approximately 34 months for the N_2O_4 in a SMO tank with bladder S/N 68-1 to reach the same degree of helium saturation that would be reached by an average production bladder in 2 days. This would indicate that in missions of lesser duration, perhaps even 1 year, temperature cycling within reasonable limits could be tolerated without gas bubble formation within the bladder, since the propellant would not be saturated and gas should not go out of solution. However, should the temperature cycling range be great enough to drive some gas out of solution as the temperature decreases, the very low permeation rate of the foil laminate bladder should allow the liberated gas to return to solution before it can be replaced in solution by permeated gas from the gas side of the bladder.

V. CONCLUSIONS

Based on analysis of test results and laboratory evaluation, the following conclusions have been made:

A. The combination of an aluminum foil laminate as a permeation barrier together with an undersized cylindrical section is a valid design concept in Apollo RCS tank teflon bladders. The foil laminate will remain an effective permeation barrier after normal launch-boost dynamic environments and the undersized configuration will not cause damage to the foil. This conclusion is greatly substantiated by the successful employment of teflon bladders of the Apollo Command Module oxidizer size, containing an aluminum foil laminate, on the Lunar Orbiter velocity control system oxidizer tanks. These bladders were qualified and were used for five Lunar Orbiter missions of durations up to 339 days. These bladders were approximately 7 mil in total thickness, utilizing 1/4 mil foil as the permeation barrier.

B. The failures experienced during the vibration testing reported herein were due to bladder stiffness and could be avoided by use of a thinner film construction and/or a change in the attachment of the bladder ends to the diffuser tube.

VI. RECOMMENDATIONS

Since the undersized bladder with aluminum foil laminate has been shown to be a valid design for Apollo-type teflon bladders, it is recommended that further studies be conducted to overcome the design problem at the bladder-to-diffuser interface. This problem could be solved by lessening the bladder stiffness and by altering the design of the diffuser/bladder interface itself.

Additional studies should also be conducted in the following areas:

- Effect of long-term propellant exposure on teflon/aluminum bond strength and flexure life.
- Nondestructive technique for measuring film thickness of teflon/aluminum foil bladders.
- Further refinement of fabrication techniques in the areas of eliminating inter-laminate bubbles, improved sintering/quenching techniques, and elimination of contamination between laminates.

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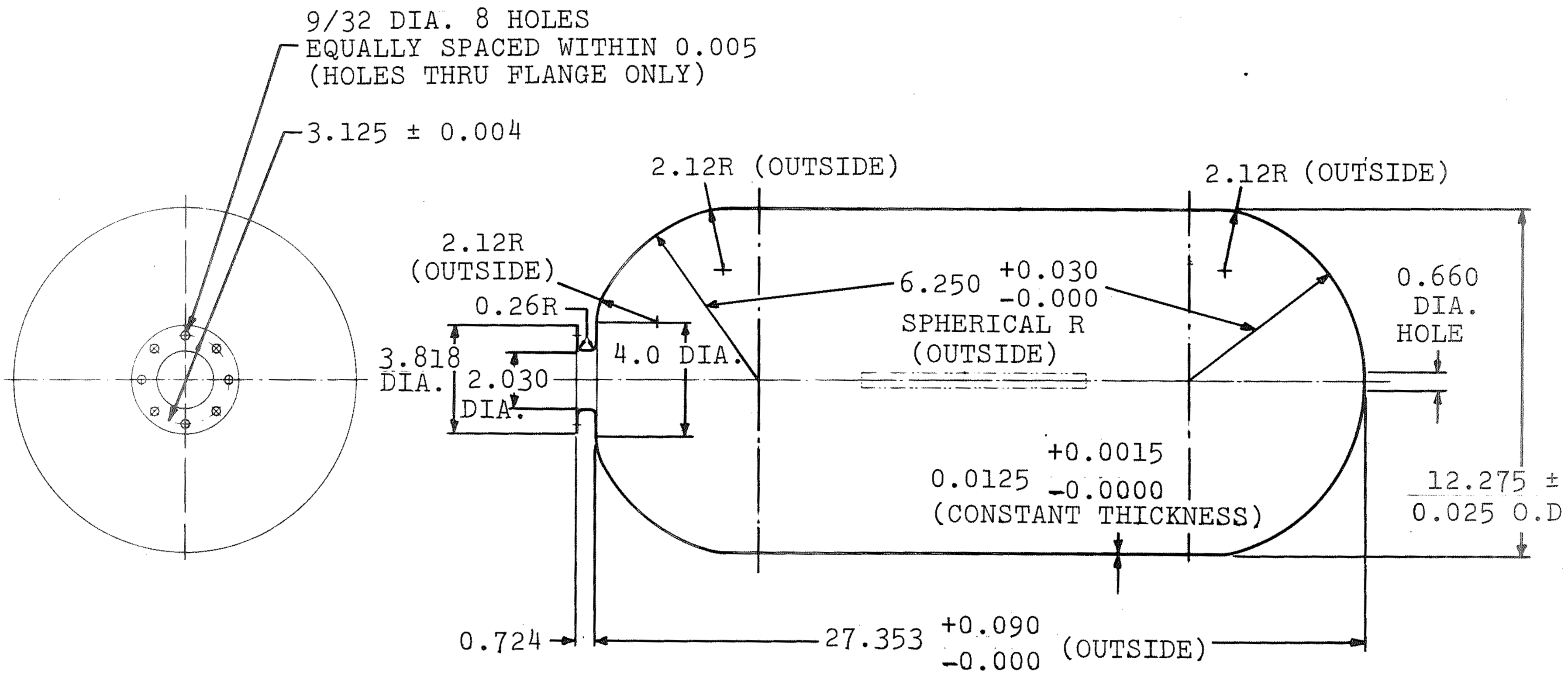
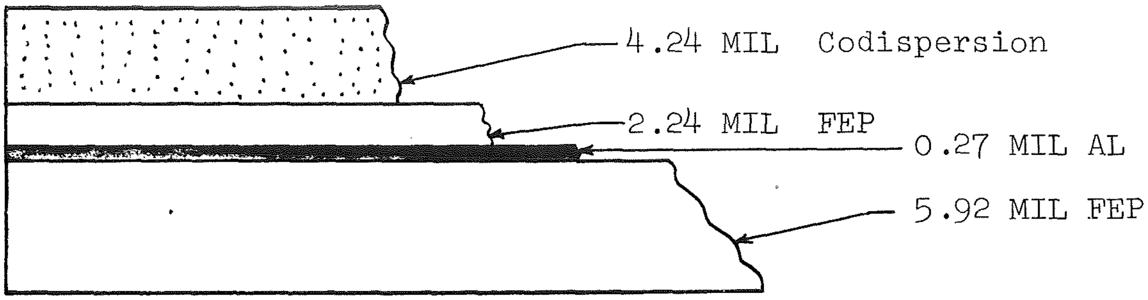


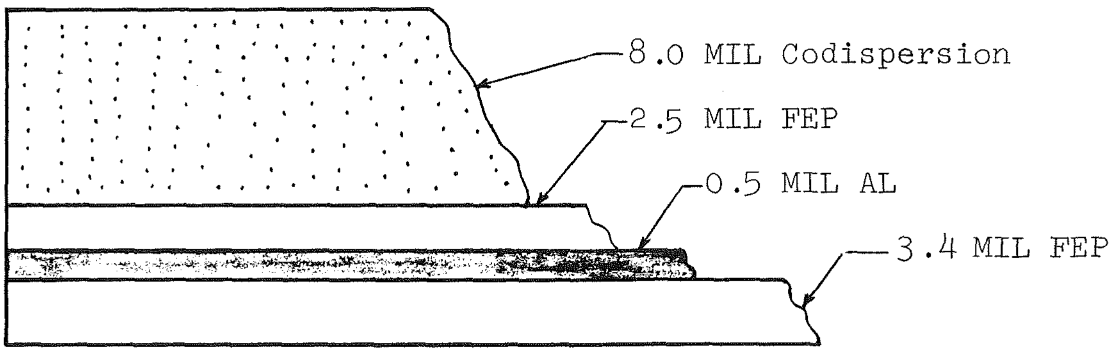
FIGURE 1. EXPULSION BLADDER

BLADDER S/N 68-1



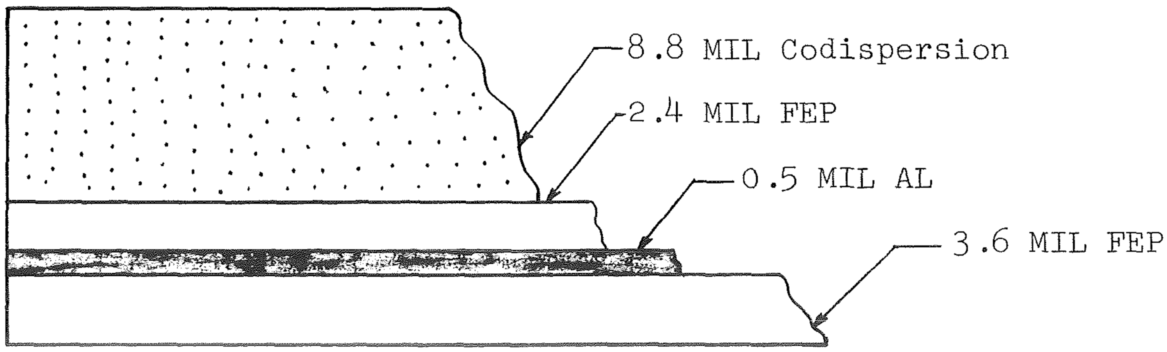
TOTAL THICKNESS = 12.67 MIL

BLADDER S/N 69-1



TOTAL THICKNESS = 14.4 MIL

BLADDER S/N 70-1



TOTAL THICKNESS = 15.3 MIL

FIGURE 2. BLADDER LAMINATE CONSTRUCTION

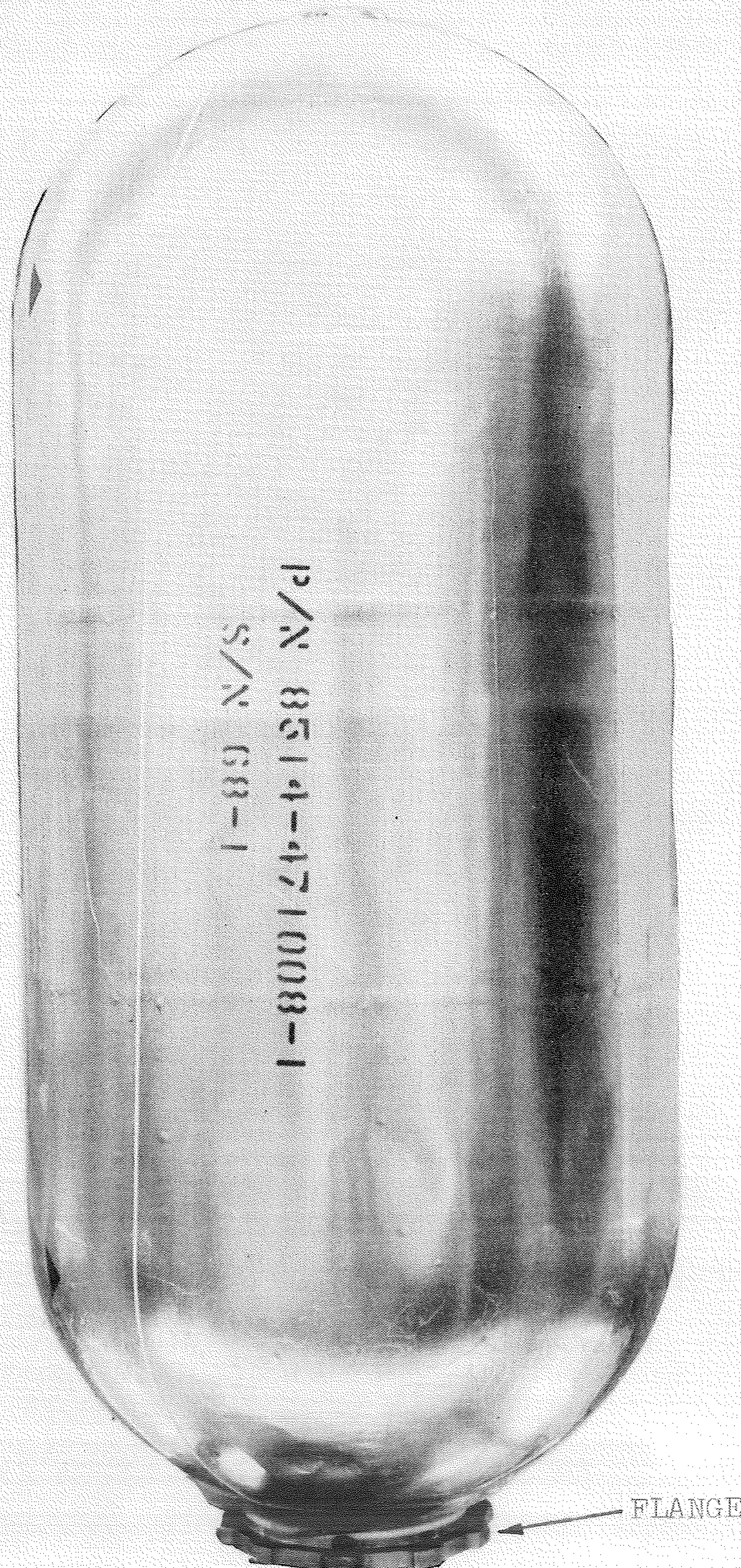


FIGURE 3. TYPICAL BLADDER

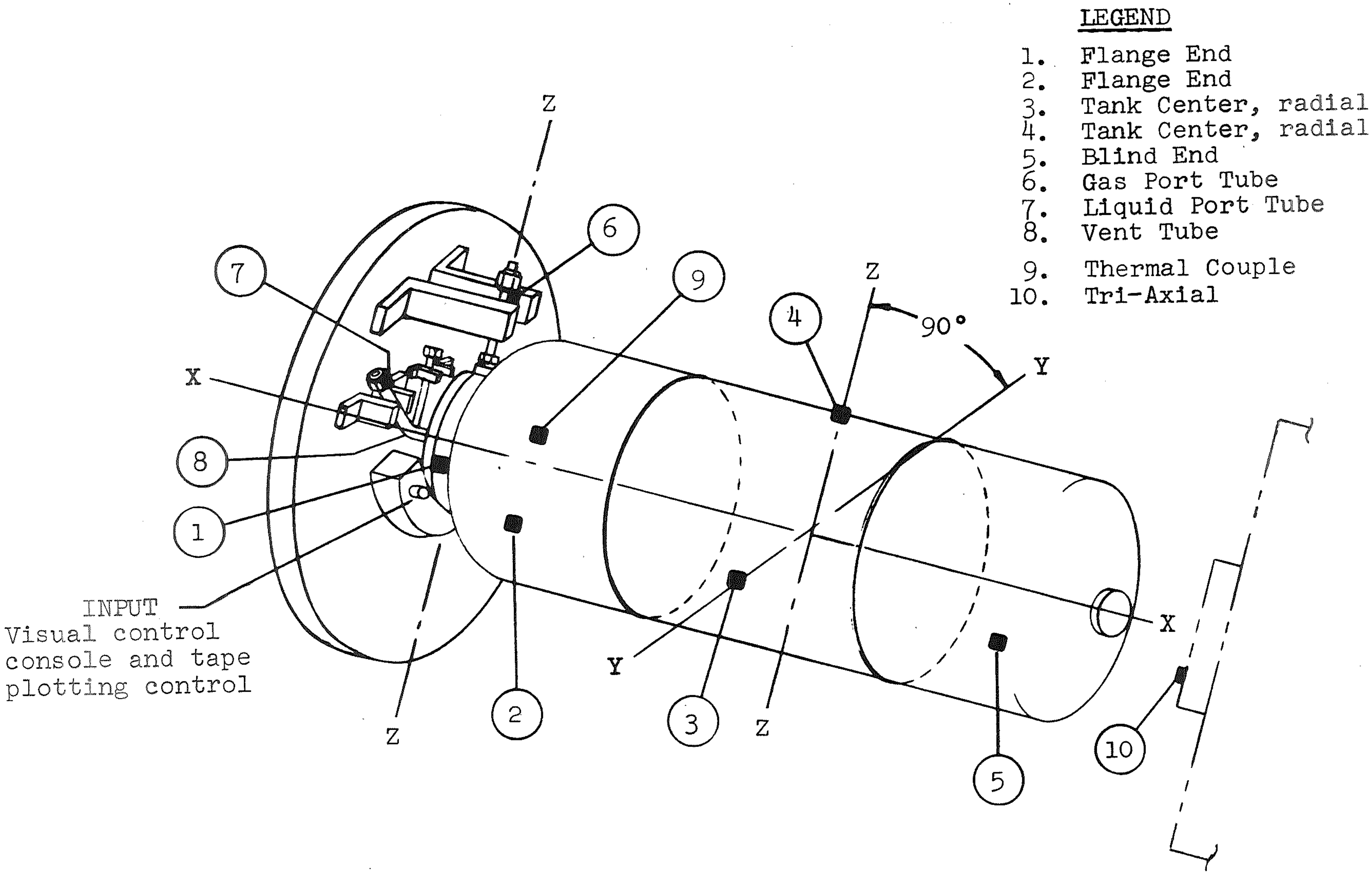
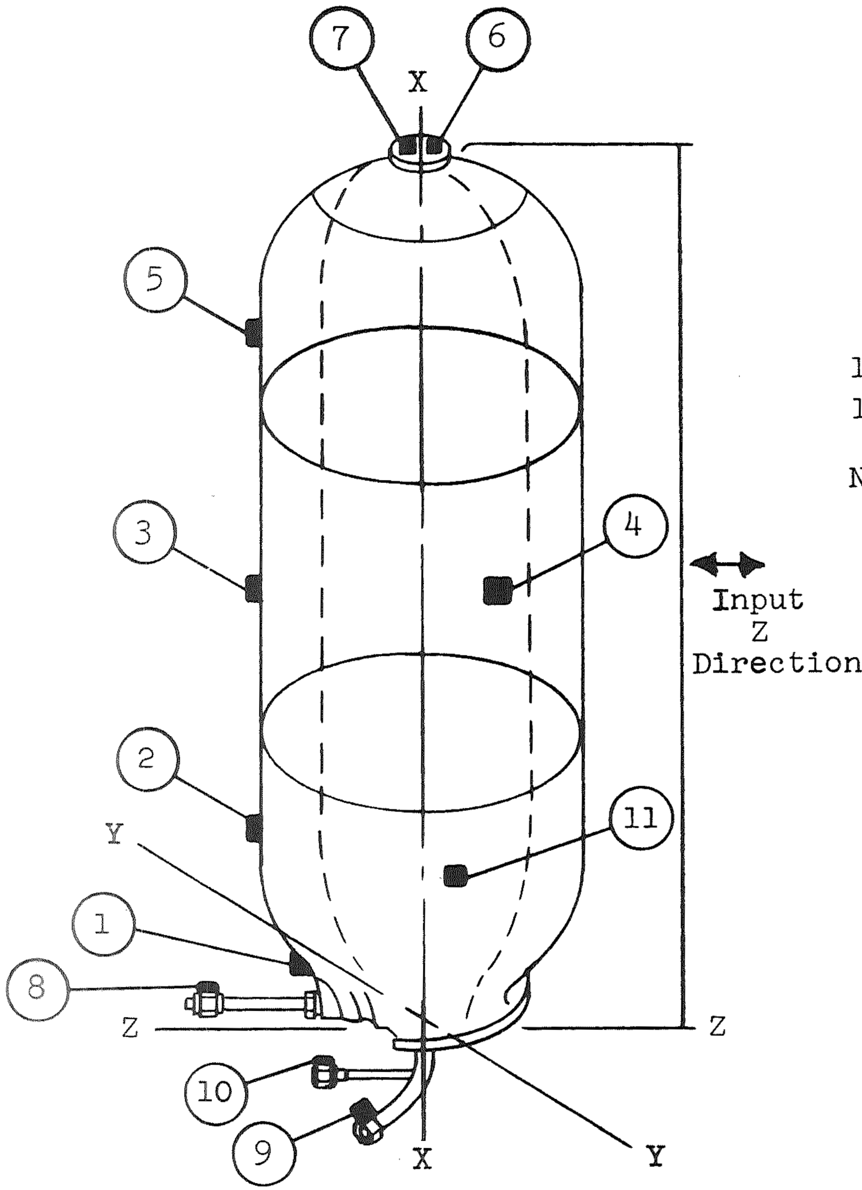


FIGURE 4. LONGITUDINAL X-AXIS VIBRATION PICKUP LOCATIONS



LEGEND (For Z-axis)

1. Flange End
2. Flange End
3. Tank Center, radial
4. Tank Center, radial
5. Blind End
6. Trunnion Face, longitudinal
7. Trunnion Face, lateral
8. Gas Port Tube
9. Liquid Port Tube
10. Vent Tube
11. Thermal Couple

NOTE:

Input pickup on fixture for visual control of console and tape plotting control.

NOTE:
For Y-Axis, Rotate Pickup Locations 90°.

FIGURE 5. LATERAL Z-AXIS VIBRATION PICKUP LOCATIONS

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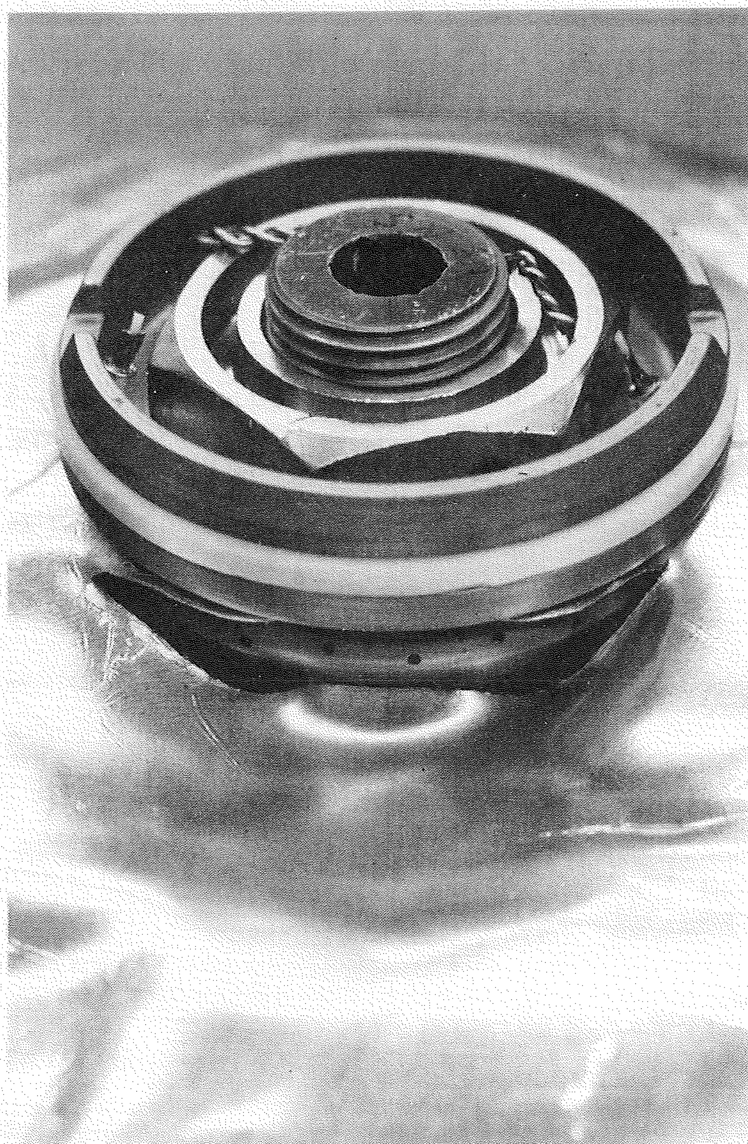


FIGURE 6. BLADDER S/N 69-1 FAILURE

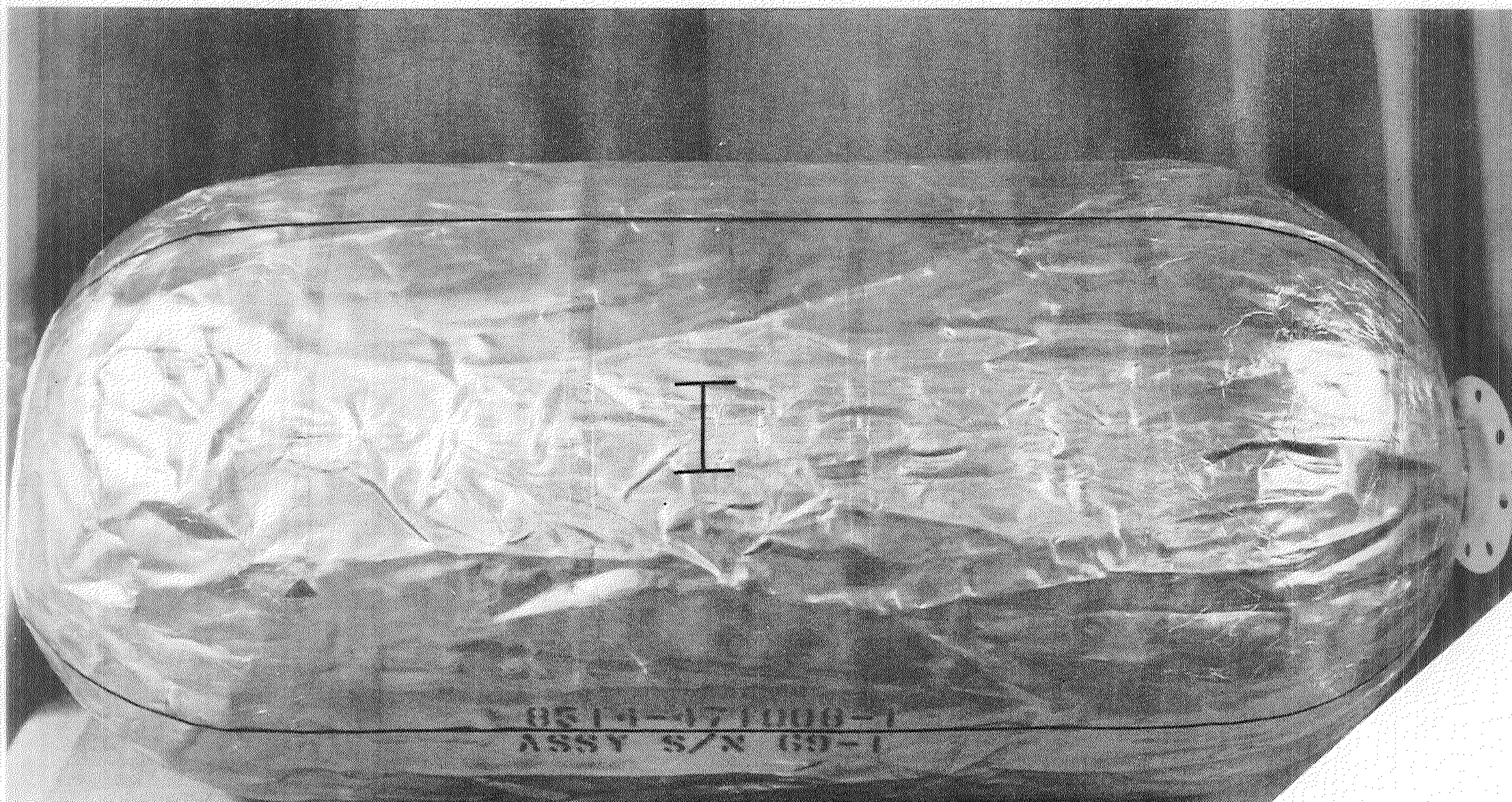
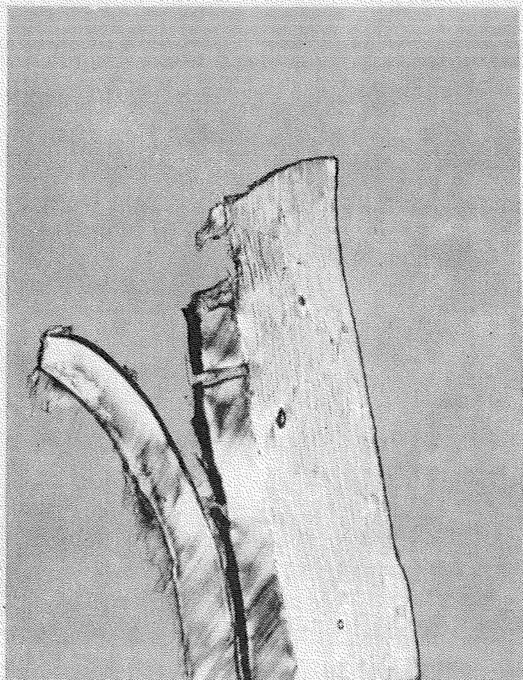
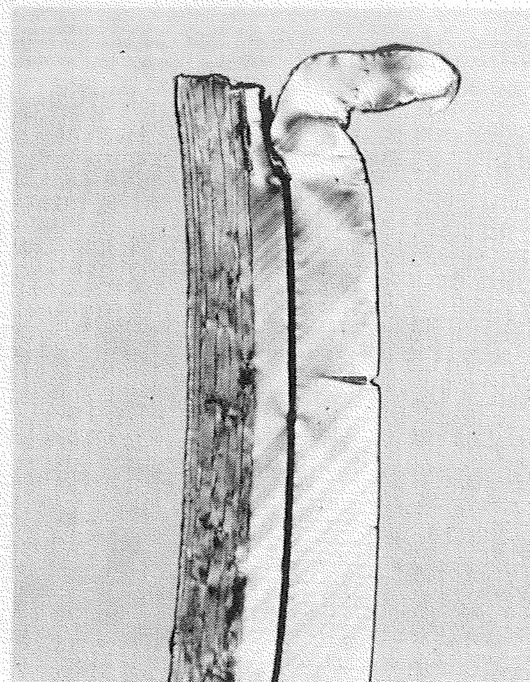


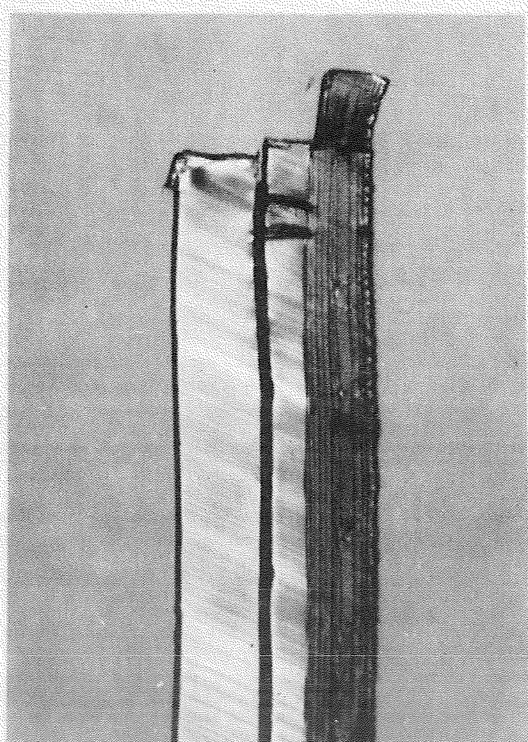
FIGURE 7. BLADDER S/N 69-1 POST-VIBRATION TEST CONDITION



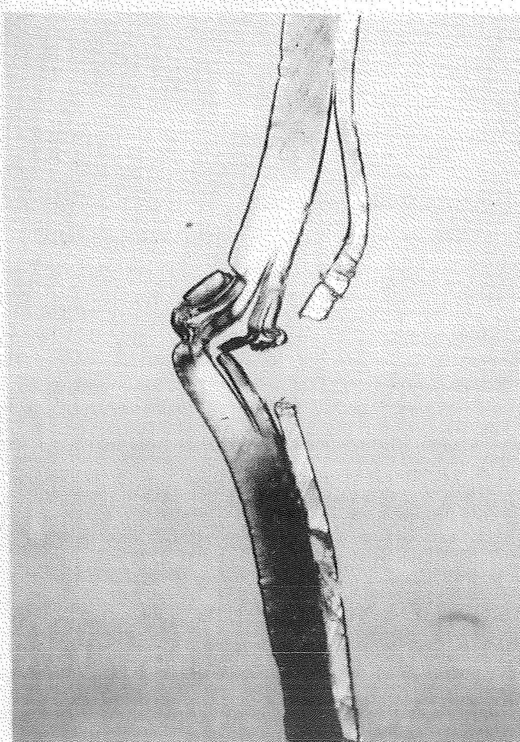
69-1 Failure



68-1 Failure



Lab Specimen - Repetitive Flexing Plus Shock



Lab Specimen - Rolling-Fold Damage

FIGURE 8. BLADDER S/N 69-1 AND 68-1 FAILURE CROSS-SECTION

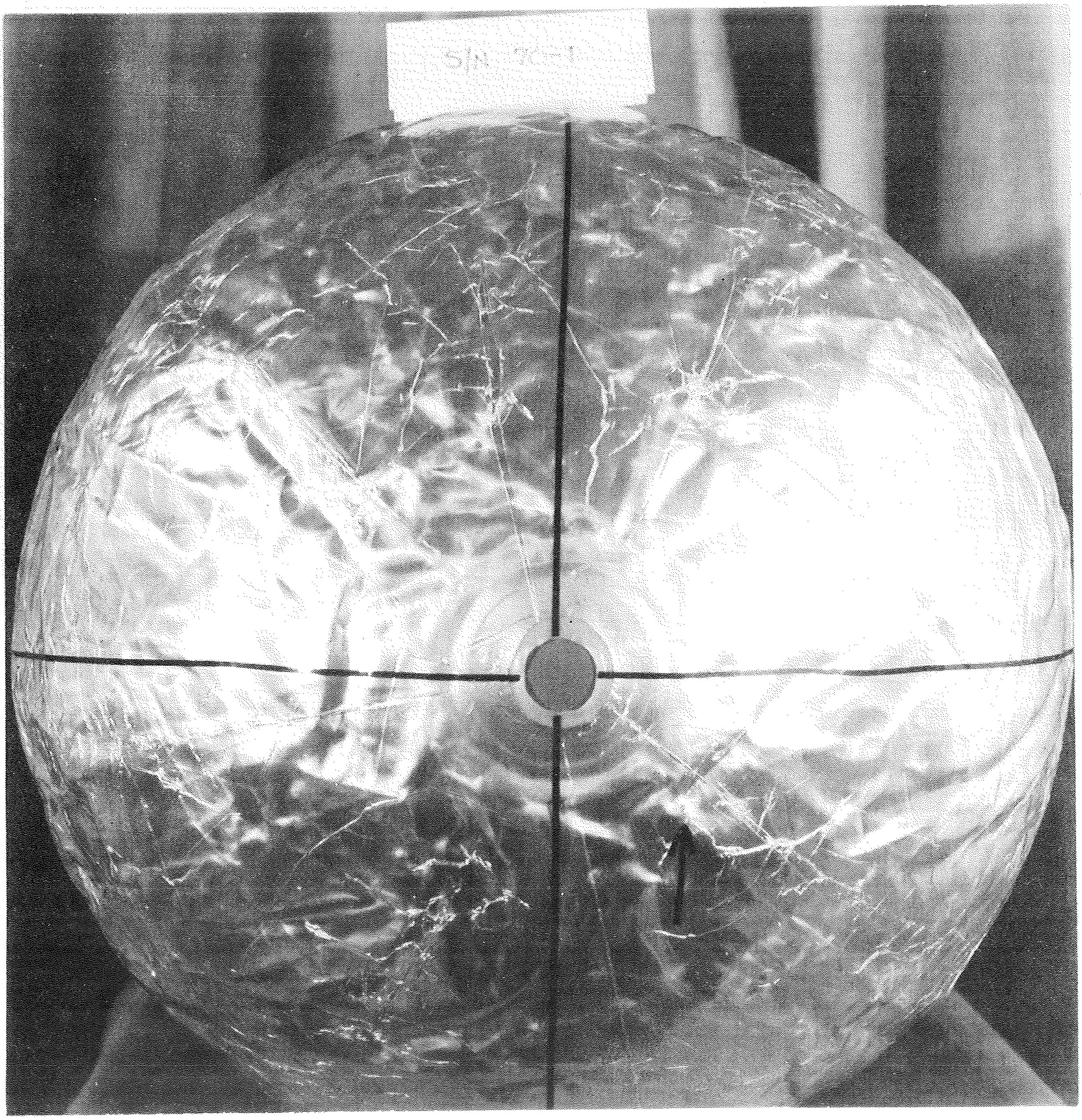


FIGURE 9. BLADDER S/N 70-1 FAILURE

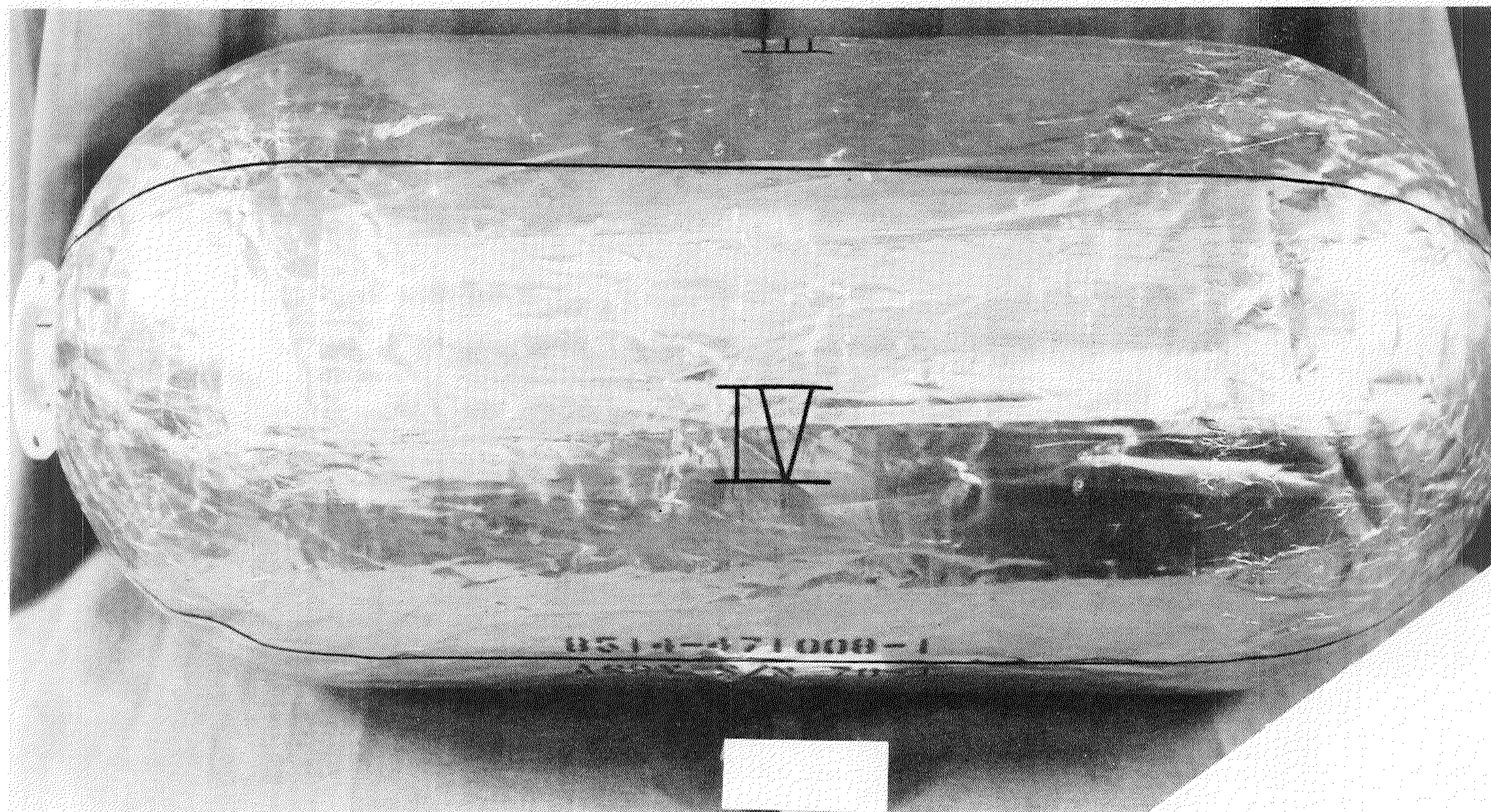
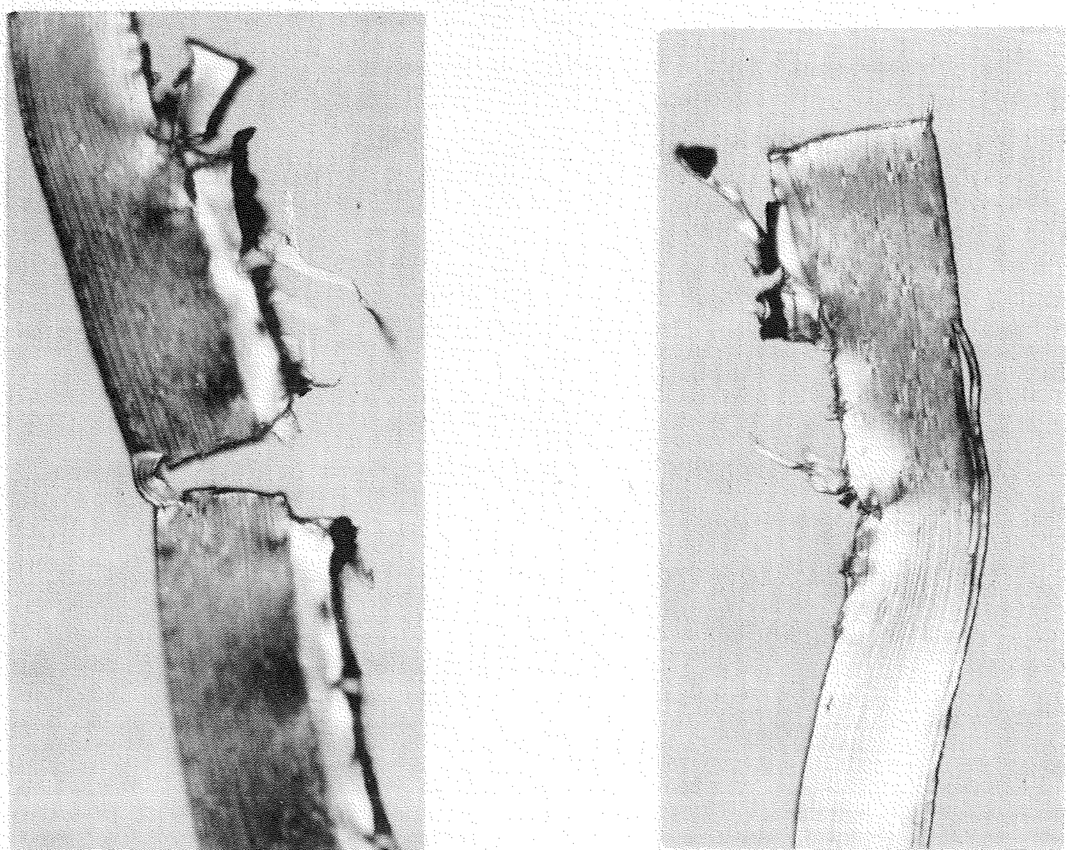


FIGURE 10. BLADDER S/N 70-1 POST-VIBRATION TEST CONDITION



(A) Failure Area

(B) Area Adjacent to Failure

FIGURE 11. BLADDER S/N 70-1 FAILURE CROSS-SECTION

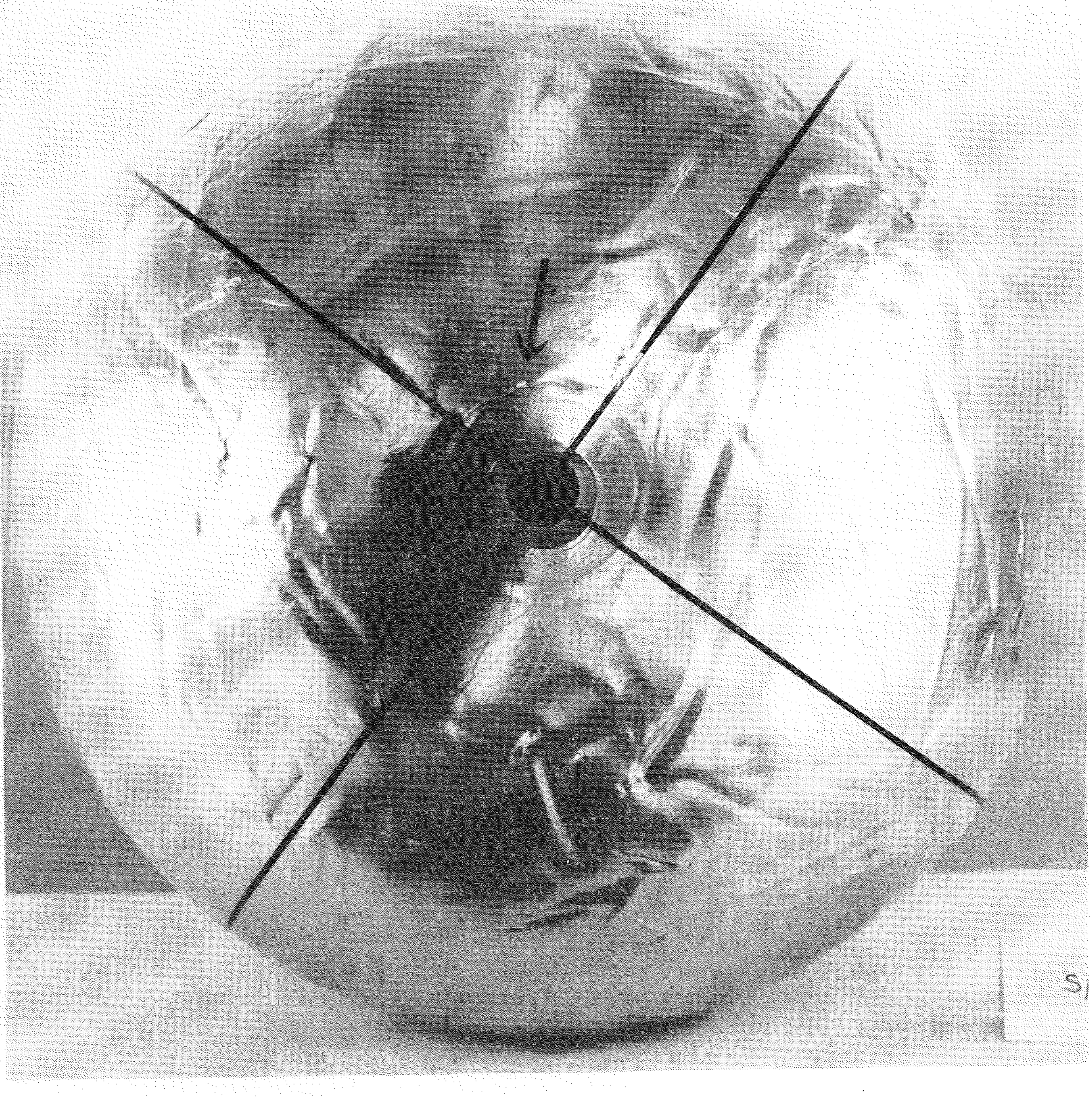


FIGURE 12. BLADDER S/N 68-1 FAILURE

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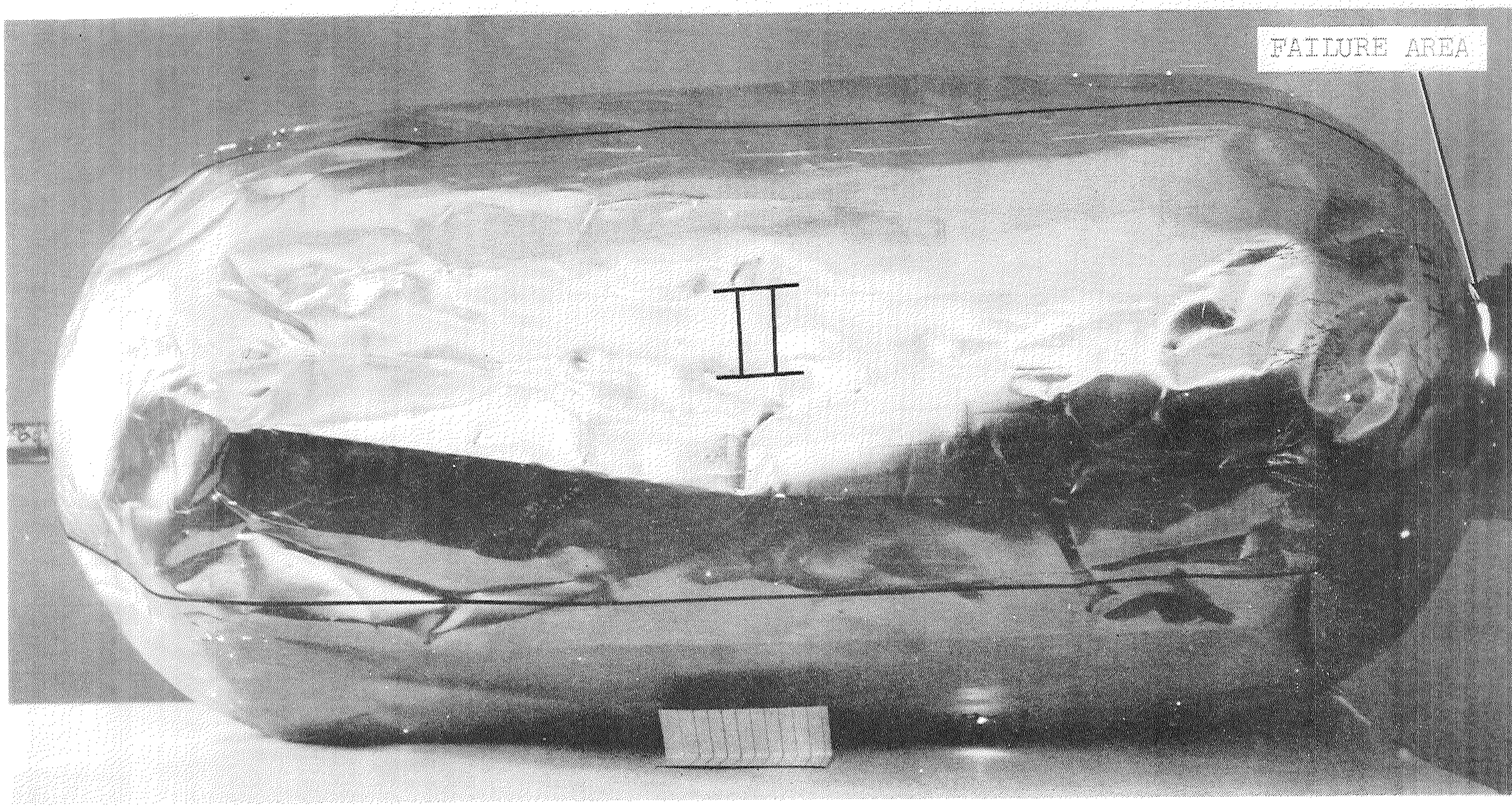

FIGURE 13. BLADDER S/N 68-1 POST-VIBRATION CONDITION
(WITH INTERIOR LIGHTING)

TABLE 1. BLADDER LEAKAGE RATES

Bladder S/N 68-1	Leakage Rate*
Pre-Test	< 0.5**
Post 5 min X-axis Random	0.1
Post 10 min X-axis Random and Sine	0.2
Post Z-axis Sine and 15 sec Random	247/10 sec
Bladder S/N 69-1	
Pre-Test	< 0.5**
Post X-axis Random and Sine	0.7
Post Z-axis Sine and 2 min Random	Gross
Bladder S/N 70-1	
Pre-Test	0.8***
Post X-axis Sine and Random	3.2
Post Z-axis Sine and Random	160/15 sec

* scc/15 min Helium at 10 psig unless otherwise noted.

** Initial leakage test performed using standard production leak test apparatus not sensitive below 0.5 scc/15 min. Other leakage tests performed using more-sensitive laboratory apparatus.

*** Pre-vibration leakage test was made after the Task E expulsion tests, including disassembly and reassembly operations.

TABLE 2. BLADDER VIBRATION TIME

	Bladder S/N		
Axis	68-1	69-1	70-1
X-Axis Sine	7 min 45 sec	5 min 41 sec	5 min 29 sec
X-Axis Random	19 min 5 sec	19 min 0 sec	16 min 54 sec
Z-Axis Sine	7 min 40 sec	5 min 35 sec	5 min 5 sec
Z-Axis Random	1 min 0 sec*	6 min 49 sec*	18 min 43 sec*
Total	35 min 30 sec	37 min 5 sec	46 min 11 sec

*Bladder Failure

NOTE: Total random vibration time includes all equalization time at low level and high level.

TABLE 3. BLADDER S/N 69-1 TANK RESPONSE TO SHOCK IMPULSE INPUT

Accelerometer Location	+ Peak (g)	- Peak (g)
No. 1 Flange End	77.5	108
No. 3 Tank Center-Radial	225	167
No. 6 Trunnion Face - Long. (Retainer End)	78	52
No. 7 Trunnion Face - Lat. (Retainer End)	47	65
Input	51	37

TABLE 4. COMPARISON OF Z-AXIS RANDOM VIBRATION RESPONSE LEVELS

Accelerometer	GRMS		
	Bladder 69-1	Bladder 70-1	Bladder 68-1
No. 1 Flange End (Bottom)	40	-	39
No. 3 Tank Center-Radial	47	35	58
No. 5 Blind End (Top)	56	34	96
No. 6 Trunnion Face - Long.	55	35	125
No. 7 Trunnion Face - Lat.	-	-	54
No. 1 Input	13.4	13.6	15

SIGNATURES

(Report Approval)

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Defense Contracts
Administration Service
Coordination